Pedobiologia 31, 339—354 (1988)
VEB Gustav Fischer Verlag Jena

Rijksinstituut voor Natuurbeheer, Arnhem, The Netherlands

The influence of management practises on the microarthropod community of grassland

H. Siepel and C. F. van de Bund

With 7 figures

(Accepted: 87-09-27)

1. Introduction

This paper will focus on the effects of management measures such as fertilizing, mowing, and grazing on microarthropods in grasslands on sandy soils. Preliminary observations indicated a reduction of microarthropods in intensively managed grasslands. Because these observations were in contradiction with results published by many authors [reviewed by Marshall (1977)] a detailed investigation of the influence of grassland management on the abundance and species composition of the microarthropod community has been started.

Marshall (1977) concluded in his review that the soil fauna in general increased in numbers and species when fertilizers were used, although temporary reductions are observed. The increase is partly explained by a direct contribution of species to the soil fauna with the added manure and partly by an indirect effect of increase in prey populations favourable for predators. On the contrary, Edwards & Lofty (1974) measured a decrease of soil mites and springtails with increased annual supplied nitrogen levels of 48, 96, 144 kg $N \times ha^{-1} \times a^{-1}$. Żyromska-Rudzka (1976) observed a decrease in Acari and an increase of Collembola in highly fertilized plots (annual supply of nitrogen: 360 $kg \times ha^{-1} \times a^{-1}$). The plots received this amount of nitrogen for only three years which might explain the difference compared with the results of Edwards & Lofty (1974). Most investigations reviewed by Marshall (1977) have been carried out at lower nitrogen levels e.q. Höller (1962) and Höller-Land (1962) (nitrogen level $\pm$ 20 kg $N \times ha^{-1} \times a^{-1}$). The type of management seems also to be important for microarthropods. Increasing intensity of sheep grazing reduces the numbers of Collembola (King *et al.*, 1976; King & Hutchinson, 1976; Walsingham, 1976). Rottman & Capinera (1983) measured a higher population density in exclosures than in the grazed plots. The numbers of Acari are reduced with an increase of sheep grazing (King & Hutchinson 1976). In some cases mowing seems to be favourable for mites. Southwood & Van Emden (1967) observed a higher density of Acari in cut grasslands than in uncut grasslands.

Apart from the separate effects of fertilization level and management type on the microarthropod community, we will pay attention to the influence of their interaction. Often a higher fertilization level is strongly correlated with a more intensive use of the grassland. We will try to separate several environmental factors, including fertilization and other management practices, in order to clarify which factor accounts for the larger part of the variation observed in the numbers and presence of species. Therefore, we used a new technique in multivariate analysis called canonical correspondence analyses (Braak 1986).

2. Description of the areas

Eight grasslands have been investigated. The grasslands are located near Arnhem (fig. 1) and are situated on an acid nutrient poor sandy soil. The grasslands are grouped in three fertilization levels: no fertilization, low fertilization (50 kg N $ha^{-1} \times a^{-1}$) and high fertilization (380—390 kg $N \times ha^{-1} \times a^{-1}$). In each level three kinds of management are compared; grazing by cattle, mowing, and absence of

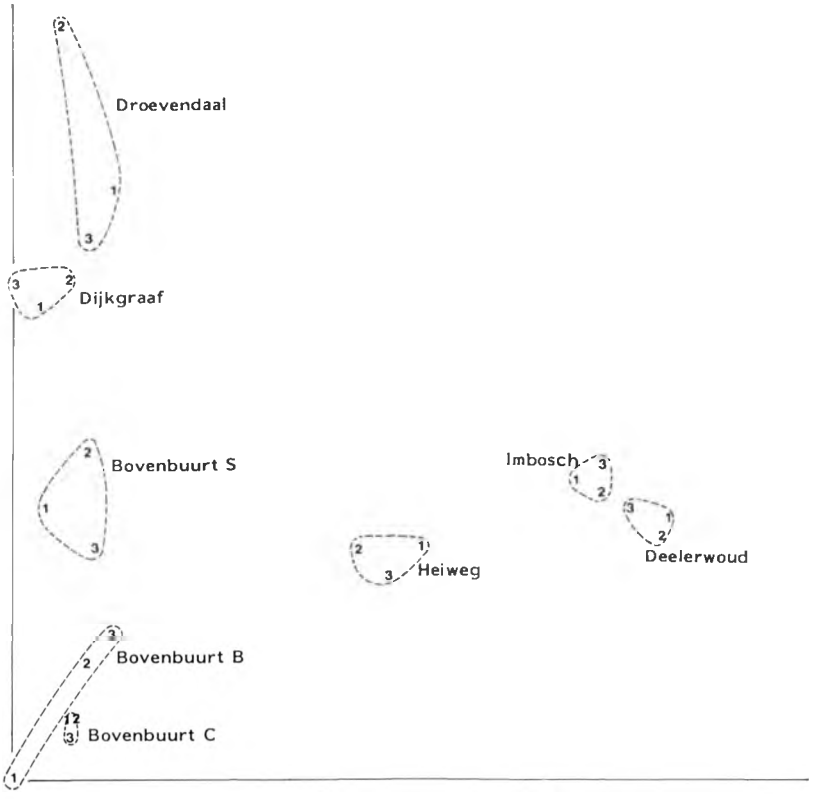

Fig. 1. Investigated grassland sites and plots. Detrended correspondence analysis ordination diagram, based on the abundance of all microarthropods.

management measures. High fertilization and absence of management cannot be continued in practice so this situation is missing. For the same practical reason, the slightly fertilized grassland which should not have management measures is mown once a year in spring. In each grassland, three plots have been chosen randomly. The minimal distance between plots is 30 m so the assumption has been made that the plots are independent in the sampling of microarthropods. Depending on the management of the grasslands there are differences in vegetation.

A brief description of the vegetation and management per grassland is given in table 1. Coordinates of the grassland according to the European Invertebrate Survey (EIS) are given as well (Tol, 1983). Data on the biomass per plant species and soil characters are presented in appendix 1. Numbers of the grasslands can be found in fig. 1. Elzebroek (1982) gives a detailed description of vegetation, plant production, and animal grazing of grasslands 4, 5 and 6. The management of the grasslands has been kept constant for at least ten years with an exception for grassland 3; the grazing by Highland cattle started in 1982.

3. Sampling method

Soil samples were taken on 20 November 1984 and 20 May 1985. In this way the maximum numbers in most groups of mites are sampled (Holler, 1962). Four soil cores were taken per plot at both dates, yielding 24 cores per site in total. The cores have a depth of 5 cm and a volume of 98 cm^3. Extraction of the animals took place for five days in a Berlese Tullgren funnel. Temperature was increased during the period from 35 to 45 °C. Ethanol 70 % has been used as a conservation fluid in the funnel. The mites and springtails obtained were put into lactic acid 40 % and identified. Identification and nomenclature is according to Gisin (1960) for Collembola, Hammen (1952) and Sellnick (1928, 1960) for Cryptostigmata, Karg (1971) for Gamasina, Türk & Türk (1959) and Hughes (1976) for Tyroglyphidae, Scheucher (1959) for Anoetidae, Krczal (1959) for Pyemotidae, Karafiat (1959) for Scutacaridae and Baker & Wharton (1952) for higher taxa of Acarina.

Table 1. Brief description of the grasslands under study

Grass-land	Location/EIS coordinates	Management	Production	Dominant plant species
1	Deelerwoud nature reserve N.E. of Arnhem (195, 221)	no management	2,000 kg × ha $^{-1}$ × a^{-1}	*Avellana flexuosa* *Calluna vulgaris* *Vaccinium myrtillus*
2	Heiweg National Park De Hoge Veluwe N. of Arnhem (194, 216)	mown once a year	2,000 kg × ha^{-1} × a^{-1}	*Galium saxatile* *Luzula campestris* *Agrostis tenuis* *Avellana flexuosa*
3	Imbosch National Park Veluwezoon (196, 123)	grazed by Scottish Highland cattle (30 animal grazing days × ha^{-1} × a^{-1})	2,000 kg × ha^{-1} × a^{-1}	*Avellana flexuosa* *Vaccinum vitis-idaea*
4	Bovenbuurt C N. of Wageningen (206, 203)	fertilization: 50 kg × N × ha^{-1} × a^{-1} 100 kg K_2O × ha^{-1} × a^{-1} mown once a year	8,000 kg × ha^{-1} × a^{-1}	*Arrhenatherum elatius* *Holcus lanatus* *Poa trivialis* *Lolium perenne* *Cerastium fontanum* *Dactylis glomerata*
5	Bovenbuurt B N. of Wageningen (206, 203)	fertilization: 50 kg N × ha^{-1} × a^{-1} 100 kg N_2O × ha^{-1} × a^{-1} mown twice a year (June, September)	8,000 kg × ha^{-1} × a^{-1}	*Rumex acetosa* *Ranunculus acris* *Holcus lanatus* *Alopecuris pratensis* *Lolium perenne* *Arrhenatherum elatius*
6	Bovenbuurt S N. of Wageningen (206, 203)	fertilization: 50 kg N × ha^{-1} × a^{-1} grazed by young bulls (745 animal grazing days × ha^{-1} × a^{-1})	8,000 kg × ha^{-1} × a^{-1}	*Lolium perenne* *Holcus mollis* *Ranunculus repens* *Holcus lanatus*
7	Droevendaal N. of Wageningen (206, 203)	fertilization: 380 kg N × ha^{-1} × a^{-1} 460 kg K_2O × ha^{-1} × a^{-1} 140 kg P_2O × ha^{-1} × a^{-1} mown every month from May till October	15,000 kg × ha^{-1} × a^{-1}	*Lolium perenne* *Poa annua*
8	Dijkgraaf N. of Wageningen (206, 203)	fertilization: 390 kg N × ha^{-1} × a^{-1} 120 kg K_2O × ha^{-1} × a^{-1} 45 kg P_2O × ha^{-1} × a^{-1} grazed by cattle (1,140 animal grazing days × ha^{-1} × a^{-1})	15,000 kg × ha^{-1} × a^{-1}	*Lolium perenne* *Poa trivialis* *Poa annua* *Alopecurus geniculatus*

4. Results

4·1. Extraction of animals from soil cores

In November 1984 samplings totalling 32,808 microarthropods were obtained in 217 different taxonomic groups. In May 1985 samplings totalling 11,011 were obtained in 179 taxonomic groups. Most animals were identified to the species level (Collembola, Acari, Mesostigmata, Cryptostigmata, Astigmata). Only the Acari, Trombidiformes were identified the generic level or even to the family level.

Table 2. Diversity indices, evenness indices, number of species and number of individuals calculated per plot for microarthropods in grassland, sampled November 1984

Site Plot	diversity indices		evenness indices					number of species	number of individuals
	Simpson	Shannon-Wiener	J[1]	E 1.0	E 2.0	F 1.0	F 2.0		
Deelerwoud 1	0.083	3.183	0.728	0.305	0.497	0.296	0.475	79	2,471
Deelerwoud 2	0.087	3.110	0.718	0.295	0.513	0.286	0.490	76	2,422
Deelerwoud 3	0.063	3.378	0.753	0.329	0.540	0.322	0.523	89	2,869
Heiweg 1	0.142	2.693	0.688	0.296	0.477	0.281	0.439	50	1,213
Heiweg 2	0.147	2.853	0.706	0.304	0.393	0.292	0.356	57	925
Heiweg 3	0.087	3.043	0.737	0.338	0.548	0.327	0.526	62	1,253
Imbos 1	0.101	2.732	0.688	0.290	0.644	0.276	0.619	52	2,727
Imbos 2	0.168	2.436	0.620	0.224	0.521	0.209	0.475	50	2,635
Imbos 3	0.157	2.660	0.647	0.234	0.447	0.222	0.405	60	2,870
Bovenbuurt C1	0.478	1.395	0.369	0.092	0.518	0.071	0.359	44	2,071
Bovenbuurt C2	0.074	3.080	0.762	0.382	0.623	0.371	0.604	57	1,632
Bovenbuurt C3	0.090	2.986	0.748	0.367	0.560	0.355	0.537	54	1,796
Bovenbuurt B1	0.206	2.349	0.584	0.187	0.463	0.172	0.406	56	1,901
Bovenbuurt B2	0.161	2.602	0.669	0.275	0.462	0.260	0.419	48	1,501
Bovenbuurt B3	0.281	2.012	0.532	0.159	0.475	0.141	0.394	47	1,548
Bovenbuurt S1	0.078	3.163	0.813	0.483	0.545	0.472	0.525	49	440
Bovenbuurt S2	0.106	2.688	0.762	0.432	0.644	0.415	0.618	34	273
Bovenbuurt S3	0.098	2.913	0.741	0.361	0.554	0.348	0.529	51	510
Droevendaal 1	0.065	3.087	0.868	0.626	0.704	0.615	0.690	35	170
Droevendaal 2	0.092	2.799	0.744	0.382	0.660	0.367	0.638	43	578
Droevendaal 3	0.119	2.643	0.727	0.370	0.596	0.353	0.565	38	574
Dijkgraaf 1	0.180	2.065	0.763	0.526	0.704	0.492	0.661	15	60
Dijkgraaf 2	0.099	2.607	0.820	0.565	0.744	0.546	0.723	24	158
Dijkgraaf 3	0.160	2.412	0.709	0.372	0.559	0.350	0.516	30	211

Table 3. Diversity indices, evenness indices, number of species and number of individuals calculated per plot for microarthropods in grassland, sampled May 1985

Pot	diversity indices		evenness indices					number of species	number of individuals
	Simpson	Shannon-Wiener	J[1]	E 1.0	E 2,1	F 1,0	F 2,1		
Deelerwoud 1	0.068	3.185	0.781	0.410	0.606	0.400	0.589	59	851
Deelerwoud 2	0.069	3.225	0.770	0.381	0.573	0.372	0.561	66	892
Deelerwoud 3	0.046	3.428	0.810	0.447	0.704	0.438	0.694	69	1,285
Heiweg 1	0.069	3.041	0.799	0.465	0.692	0.453	0.676	45	452
Heiweg 2	0.049	3.387	0.845	0.538	0.697	0.529	0.686	55	382
Heiweg 3	0.062	2.264	0.848	0.557	0.618	0.547	0.603	47	313
Imbos 1	0.112	3.009	0.747	0.362	0.439	0.350	0.410	56	579
Imbos 2	0.275	0.254	0.589	0.207	0.382	0.189	0.310	46	850
Imbos 3	0.133	2.750	0.710	0.326	0.479	0.312	0.444	48	882
Bovenbuurt C1	0.052	3.316	0.852	0.562	0.703	0.553	0.692	49	336
Bovenbuurt C2	0.055	3.216	0.818	0.489	0.732	0.479	0.721	51	649
Bovenbuurt C3	0.055	3.263	0.818	0.484	0.700	0.474	0.688	54	594
Bovenbuurt B1	0.083	2.924	0.793	0.465	0.650	0.451	0.630	40	358
Bovenbuurt B2	0.093	2.882	0.787	0.458	0.601	0.443	0.587	39	391
Bovenbuurt B3	0.006	2.828	0.783	0.457	0.557	0.442	0.529	37	485
Bovenbuurt S1	0.166	2.453	0.772	0.484	0.520	0.462	0.474	24	115
Bovenbuurt S2	0.249	2.099	0.577	0.215	0.493	0.193	0.422	38	416
Bovenbuurt S3	0.139	2.473	0.727	0.395	0.607	0.374	0.571	30	165
Droevendaal 1	0.081	2.788	0.846	0.602	0.763	0.586	0.747	27	196
Droevendaal 2	0.127	2.424	0.735	0.418	0.697	0.396	0.668	27	409
Droevendaal 3	0.170	2.327	0.723	0.410	0.574	0.385	0.528	25	201
Dijkgraaf 1	0.322	1.389	0.714	0.573	0.773	0.502	0.698	7	33
Dijkgraaf 2	0.328	1.809	0.638	0.359	0.500	0.319	0.402	17	58
Dijkgraaf 3	0.229	1.848	0.720	0.488	0.688	0.446	0.630	13	119

Table 4. Results of analysis of variance on diversity and evenness indices of microarthropod communities in grasslands, November 1984 series

	diversity indices		evenness indices				
	Simpson	Shannon-Wiener	J^1	E 1.0	E 2.1	F 1.0	F 2.1
fertilization	n.s	n.s	$p < 0.025$	$p < 0.005$	$p < 0.01$	$p < 0.005$	$p < 0.01$
management	n.s	n.s	n.s	n.s	n.s	n.s	n.s
interaction	n.s	n.s	$p < 0.01$	$p < 0.025$	n.s	$p < 0.025$	n.s

Tables 4 and 5: The indices are tested at 3 levels of fertilization (no, low and high fertilization) at 3 types of management (undisturbed, mown, grazed) and at interaction between fertilization and management. F-test, n.s. = not significant at $p = 0.05$.

Table 5. Results of analysis of variance on diversity and evenness indiced of microarthropod communities in grasslands, May 1985 series

	diversity indices		evenness indices				
	Simpson	Shannon-Wiener	J^1	E 1.0	E 2.1	F 1.0	F 2.1
fertilization	$p < 0.025$	$p < 0.001$	n.s	n.s	n.s	n.s	n.s
management	n.s	$p < 0.025$	n.s	n.s	n.s	n.s	n.s
interaction	n.s	n.s	n.s	n.s	n.s	n.s	n.s

Table 6. Results of multivariate analysis of variance for microarthropod communities in grasslands, samplings of November 1984 and May 1985.

	Nov. 1984	May 1985
fertilization		
no — low — high	$p < 0.001$	$p < 0.001$
no — low	$p < 0.025$	$p < 0.001$
management		
undisturbed — mown — grazed	$p < 0.025$	$p < 0.005$
mown — grazed	$p < 0.01$	$p < 0.01$
interaction		
fertilization — management	$p < 0.005$	$p < 0.005$

Fertilization levels, management types and interaction between fertilization and management have been tested [Wilks likelihood ratio test (SEBER, 1984)].

4.2. Diversity and evenness

Indices of diversity and evenness have been calculated (tables 2 and 3). Two diversity indices, the SIMPSON Index (column 1) and the SHANNON-WIENER index (column 2), and 5 eveness indices are presented (columns 3 to 7). The first evenness index is the commonly used index J^1 (PIELOU, 1969). The second to fifth indices give respectively: (E 1.0), the ratio between the number of abundant species and the number of all species; (F 1.0), HURLBERT's modification of the former (HURLBERT 1971) being a substraction of the minimum to be obtained in any community; (E 2.1), the ratio between the number of very abundant species and the number of abundant species (ROTENBERRY, 1978); and finally, (F 2.1) the modification of HURLBERT (1971) of (E 2.1), ALATALO (1981) summarized these indices and made some comparisons based on artificial data. He concluded that (F 2.1) seemed the most interpretable index, but he also warned against the use of diversity and evenness indices because they have not produced much useful information in ecological studies.

Taking the remarks of ALATALO (1981) into account it is interesting whether diversity or evenness indices yield information about the influence of fertilization and management on the microarthropod community of grasslands. The diversity indices given in tables 2 and 3 of plots having no, low, and high fertilization have been tested (analysis of variance, F-test).

The same test has been carried out for plots having differences in management (undisturbed, mown, grazed) and for the interaction between fertilization level and management type. The results of these tests are presented in table 4 for the November 1984 sampling and in table 5 for the May 1985 sampling. The November series does not yield any significant differences from the influence of management; only the Shannon-Wiener index is significant. Diversity is declining in the sequence: undisturbed, mown, grazed. The evenness indices given in tables 2 and 3 plots having different fertilization levels, and different management types have been tested. The interaction between fertilization level and management type has also been tested. The results of these tests are given in table 4 for the November 1984 series and in table 5 for the May 1985 series.

Differences in fertilization level are significant for all evenness indices, but the results are hard to interpret. In undisturbed plots, fertilization yields a lower evenness, in mown plots the lowest evenness is recorded at a low fertilization level, in grazed plots it is just the other way round: a low fertilization level yields the highest evenness recorded. Interaction of fertilization and management also affects the evennes indices J, E 1.0 and F 1.0, but not the indices E 2.1 and F 2.1 which are the most interpretable (Alatalo, 1981). The May 1985 series does not yield any significant difference in evenness. It has to be concluded that either fertilization and management does not affect microarthropod communities or the measurements used, diversity and evenness indices, cannot represent differences in microarthropod communities.

Taking into account the decrease of species number and number of individuals at increasing fertilization levels (tables 2 and 3), we tend to conclude the latter. We will support this conclusion by using a more sophisticated technique for the testing of differences between plots.

4.3. Multivariate analysis of variance

We used a multivariate analysis of variance (Manova) to test the differences between microarthropod communities. At this high number of species, hypothesis matrices will soon be singular and no test can be arranged. So we had to make a selection. First we selected on frequency, only species occurring in nine or more plots of 24 remained in the analysis. In the November series remained 33 species and in the May series remained 37 species. Even these low numbers were too high for MANOVA and a second selection has to be made. We carried out a cluster analysis and in both series the analyses resulted in 6 groups of species whose representation did not result in a singular hypothesis matrix in MANOVA. Species distributions proved to be skew, so data were transformed logarithmically ($^{10}\log(x + 1)$). We used the Wilk Likelihood ratio test and calculated the F value from it using functions for two special cases ($m_H = 1$ and $m_H = 2$) (Seber 1984).

Both fertilization and management treatments yield significant differences between sites and in addition, interaction between fertilization and management is also significant in both the November 1984 sampling and the May 1985 sampling (table 6). We conclude that the sites having a different fertilization level have a different microarthropod community. Furthermore we conclude that the sites having different management types have also a different microarthropod community.

Additionally we conclude that a significant part of the variation in the microarthropod communities of the sites is not explained by differences in fertilization only or by differences in management only but is explained by the combination of both fertilization, management and the characteristics of the site.

4.4. Canonical correspondence analysis

It has been shown that differences between sites in the microarthropod fauna are significant. However, are these differences really related to fertilization and management? In fact the microarthropod fauna can respond to less conspicuous factors that also differ between the grassland samples. The differences between the microarthropod community of grasslands should therefore be explained in terms of environmental variables. Braak (1986)

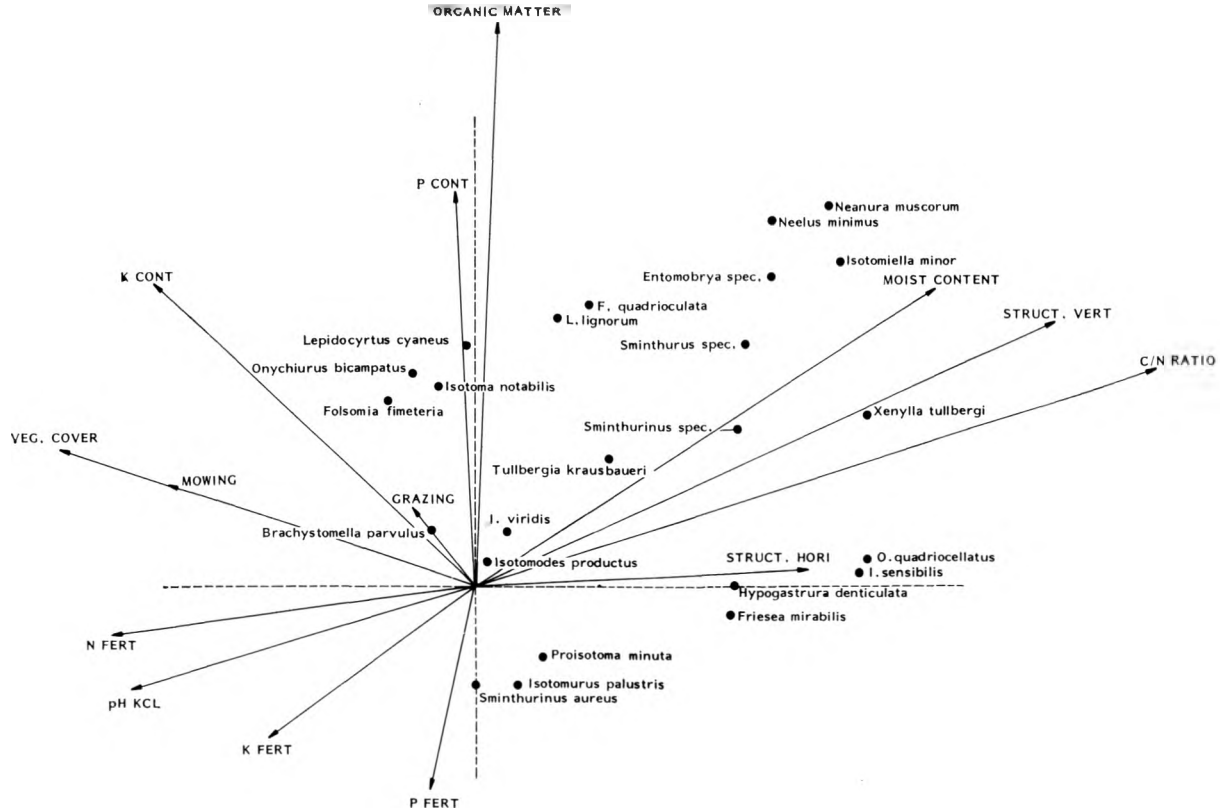

Fig. 2. Collembola sampled in November 1984. Detrended canoncial correspondence analysis ordination diagram for Collembola species(>) and environmental variables (arrows); first axis horizontally, second axis vertically. Species observed in two plots or less are not shown.
The Collembola species shown in the plot are abbreviated. The species are: *Brachystomella parvulus*, *Entomobrya spec.*, *Folsomia fimetaria*, *F. quadrioculata*, *Friesea mirabilis*, *Hypogastrura denticulata*, *Isotoma notabilis*, *I. sensibilis*, *I. viridis*, *Isotomiella minor*, *Isotomodes productus*, *Isotomurus palustris*, *Lepidocyrtus cyaneus*, *L. lignorum*, *Neanura muscorum*, *Neelus minimus*, *Onychiurus bicampatus*, *O. quadriocellatus*, *Proisotoma minuta*, *Sminthurinus aureus*, *Sminthurus spec.*, *Sminthurinus spec.*, *Tullbergia krausbaueri*, *Xenylla tullbergi*. Environmental variables are ORGANIC MATTER in top soil, MIST CONTENT in top soil, STRUCT. VERT. diversity in vertical vegetation structure, STRUCT. HORI diversity in horizontal vegetation structure, C/N RATIO in top soil, P FERT phosphate fertilization, K FERT potassium fertilization, pH_{KCl} in top soil, N FERT nitrogen fertilization, MOWING removed biomass, GRAZING number of cattle, VEG. COVER total vegetation cover, K CONT potassium content in top soil, P CONT phosphate content in top soil.

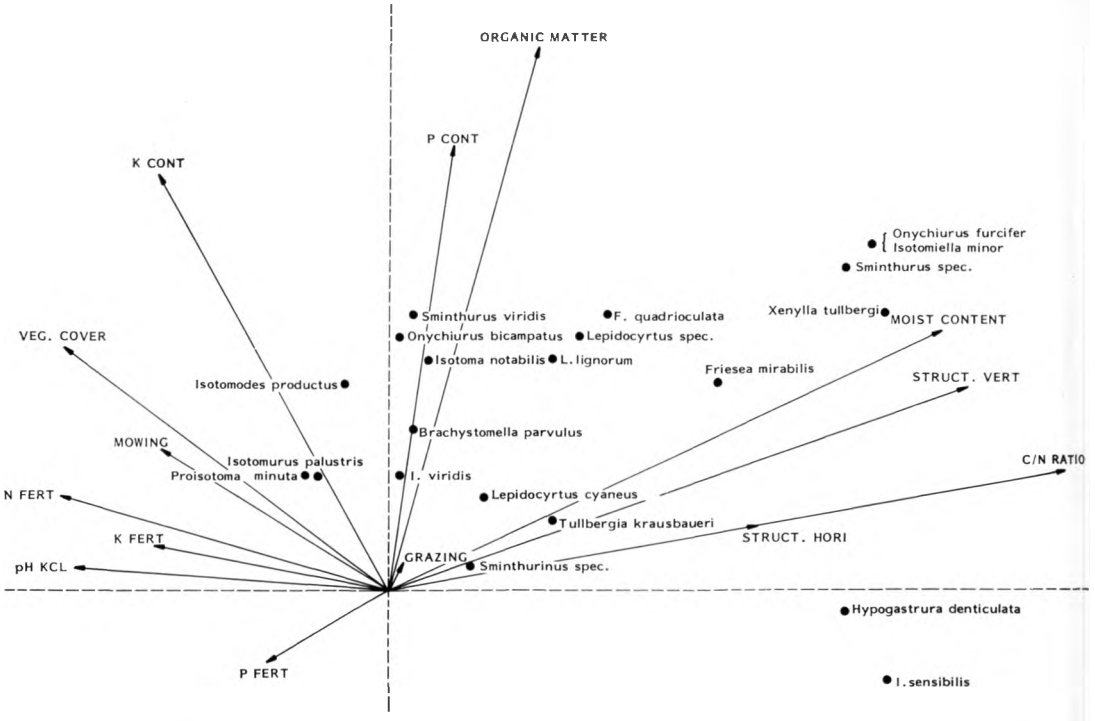

Fig. 3. Collembola sampled in May 1985. Detrended canonical correspondence analysis ordination diagram for Collembola species (>) and environmental variables (arrows); first axis horizontally, second axis vertically. Species observed in two plots or less are not shown. Collembola species are *Onychirus furcifer*, *Lepidocyrtus spec.* and *Sminthurus viridis*. See legend of fig. 2 for names other species and environmental variables.

has developed a new technique for this purpose, the canonical correspondence analysis, which is based on correspondence analysis (reciprocal averaging) developed by HILL & GAUCH (1980). It is a multivariate direct gradient analysis technique, whereby a complete set of species is related to a set of environmental variables. The mathematical technique is essentially the same as the technique of reciprocal averaging. For ecologists, however, there is an important extension because environmental data are taken into account in the reciprocal calculation of species scores and site scores.

The technique is used to decide which environmental factors are most important for the composition of the microarthropod community and which environmental factor affects a microarthropod species especially. To test the constancy of the response to environmental factors the November and the May sampling are analyzed separately. Analyses have been carried out for Collembola, Acari, Astigmata, Trombidiformes, Cryptostigmata, and Mesostigmata. Figure 1 shows the sampled plots in two dimensions. The scores of the plots on the first and second principal axes are calculated from the combined species scores of all species of that plot. The differences between sites are significant as has been calculated by MANOVA. Environmental factors are shown by vectors in the species plots.

Collembola and Cryptostigmata especially show constant responses to environmental factors. Figs. 2 and 3 show the Collembola scores on the first and second principal axes in the November 1984 and May 1985 samplings, respectively. Environmental factors highly correlated with the first principal axis are nitrogen fertilization, C/N ratio in the top soil, potassium content of the top soil, pH_{KCl}, and the vegetation cover. The amount of organic matter in the top soil is highly correlated with the second principal axis. Both axes explain

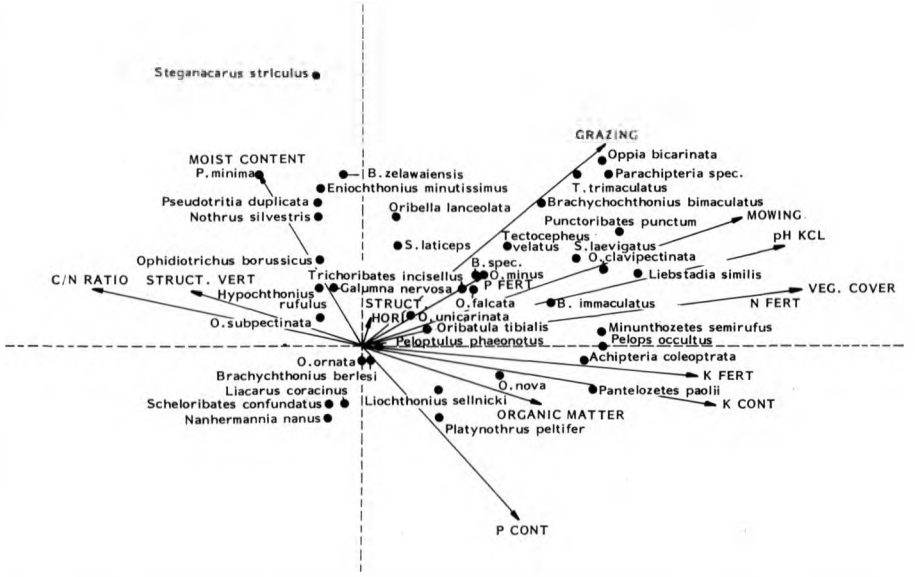

Fig. 4. Cryptostigmata sampled in November 1984. Detrended canonical correspondence analysis ordination diagram for Cryptostigmatic species (>) and environmental variables (arrows) first axis horizontally, second axis vertically. Species observed in two plots or less are not shown. The Cryptostigmatic species shown in the plot are abbreviated. The species are *Achipteria coleoptrata*, *Brachychochthonius bimaculatus*, *B. immaculatus*, *B. spec.*, *B. zelawaiensis*, *Brachychthonius berlesei*, *Eniochthonius minutissimus*, *Galumna nervosa*, *Hypochthonius rufulus*, *Liacarus coracinus*, *Liebstadia similis*, *Liochthonius sellnicki*, *Minunthozetes semirufus*, *Nanhermannia nanus*, *Nothrus silvestris*, *Ophidiotrichus borussicus*, *Oppia bicarinata*, *O. clavipectinata*, *O. falcata*, *O. minus*, *O. nova*, *O. ornata*, *O. subpectinata*, *O. unicarinata*, *Oribatula tibialis*, *Pantelozetes paolii*, *Parachipteria spec.*, *Pelops occultus*, *Peloptulus phaeonotus*, *Platynothrus peltifer*, *Punctoribates punctum*, *Pseudotritia duplicata*, *P. minima*, *Scheloribates confundatus*, *S. laevigatus*, *S. laticeps*, *Steganacarus striculus*, *Tectocepheus velatus*, *Oribella lanceolata*, *Trichoribates incisellus*, *T. trimaculatus*.
See legend of fig. 2 for names of environmental variables.

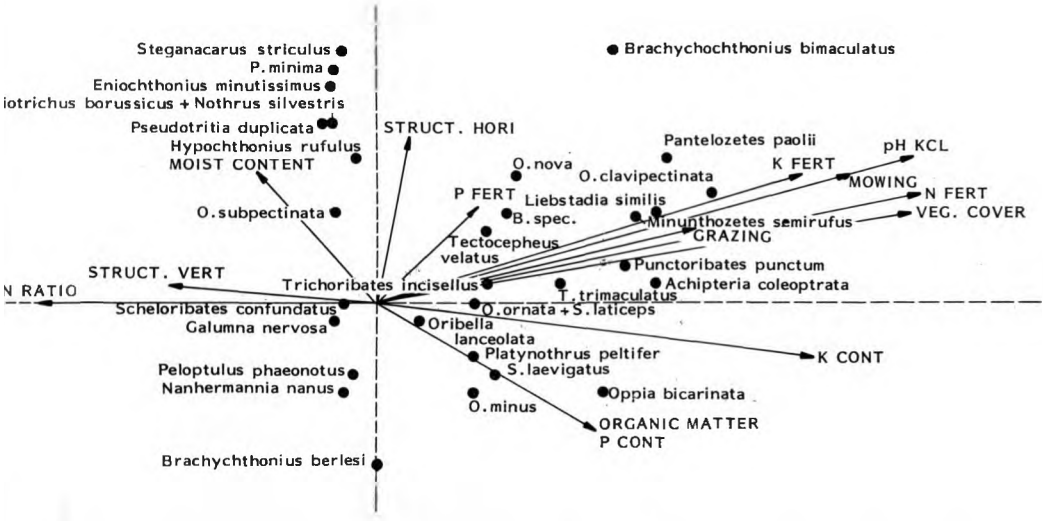

Fig. 5. Cryptostigmata sampled in May 1985. Detrended canoncial correspondence analysis ordiation diagram for Cryptostigmatic species (>) and environmental variables (arrows); first axis horizontally, second axis vertically. Species observed in two plots or less are not shown. See legend of fig. 4 for the names of the species and legend of fig. 2 for the names of the environmental variables.

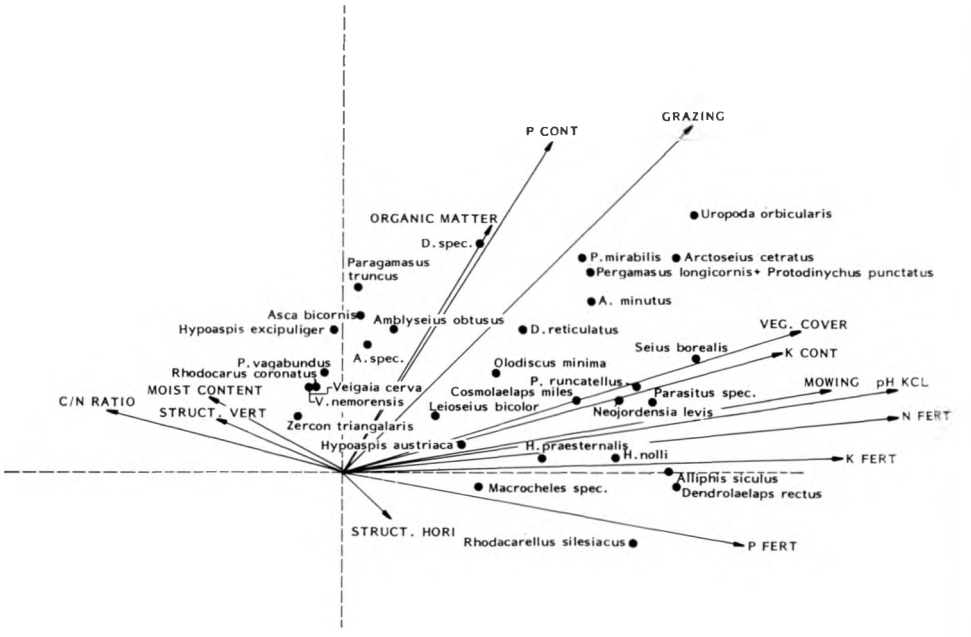

Fig. 6. Mesostigmata sampled in November 1984. Detrended canonical correspondence analysis ordination diagram for Mesostigmatic species (>) and environmental variables (arrows); first axis horizontally, second axis vertically. Species observed in two plots or less are not shown. The Mesostigmatic species shown in the plot are abbreviated. The species are: *Alliphis siculus*, *Amblyseius obtusus*, *A. spec.*, *Arctoseius cetratus*, *A. minutus*, *Asca bicornis*, *Cosmolaelaps miles*, *Dendrolaelaps rectus*, *D. reticulatus*, *D. spec.*, *Holoparasites excipuliger*, *Hypoaspis austriaca*, *H. nolli*, *H. praesternalis*, *Leioseius bicolor*, *Macrocheles spec.*, *Neojordensia levis*, *Olodiscus minima*, *Paragamasus runcatellus*, *P. truncus*, *P. vagabundus*, *Parasitus spec.*, *Pergamasus longicornis*, *P. mirabilis*, *Protodinychus punctatus*, *Rhodacarellus silesiacus*, *Rhodacarus coronatus*, *Seius borealis*, *Uropoda orbicularis*, *Veigaia cerva*, *V. nemorensis*, *Zercon triangularis*. See legend of fig. 2 for names of environmental variables.

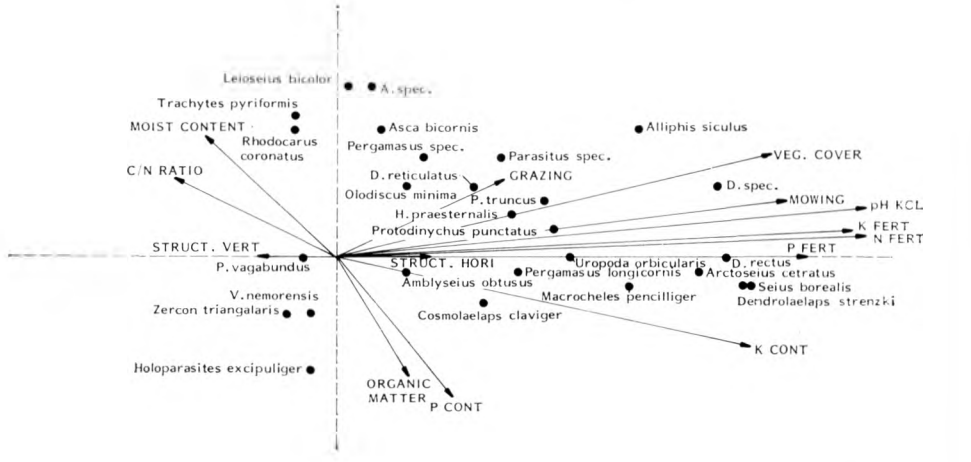

Fig. 7. Mesostigmata sampled in May 1985. Detrended canonical correspondence analysis ordination diagram for Mesostigmatic species (>) and environmental variables (arrows) first axis horizontally, second axis vertically. Species observed in two plots or less are not shown. The Mesostigmatic species shown are *Cosmolaelaps claviger*, *Macrocheles penicilliger*. *Dendrolaelaps strenzkei*, *Trachytes pyriformis*. See legend of figure 6 for names of the other species and that of fig. 2 for the names of the environmental variables.

Table 7. The proportion of explained variance and the relative position on the first principal axis for Collembola in the November 1984 and May 1985 samplings, respectively

	proportion of explained variance		position on the axis (range 1—100)	
	Nov. 1984	May 1985	Nov. 1984	May 1985
Hypogastrura denticulata	42.8	78.5	73.9	91.4
Xenylla tullbergi	88.9	82.2	99.8	97.1
Isotomiella minor	35.7	31.9	95.1	94.9
Isotoma sensibilis	73.3	54.7	98.2	98.1
Isotoma viridis	32.3	45.4	31.5	19.8

Tables 7—9:

Only species scoring higher than 30% explained variance in both the November and the May samplings are presented.

Table 8. The proportion of explained variance and the relative position on the first principal axis for Cryptostigmata in the November 1984 and May 1985 samplings, respectively.

	proportion of explained variance		position on the axis (range 1—100)	
	Nov. 1984	May 1985	Nov. 1984	May 1985
Nanhermannia nana	30.3	33.1	4.6	6.1
Hypochthonius rufulus	62.3	74.2	1.9	9.8
Eniochthonius minutissimus	67.8	49.3	2.9	5.2
Nothrus silvestris	69.6	69.9	2.3	5.4
Oppia clavipectinata	40.3	32.4	79.5	89.9
Oppia subpectinata	59.3	57.8	1.7	5.4
Pantelozetes paolii	36.8	47.5	86.2	100.0
Liebstadia similis	58.0	59.9	86.8	95.8
Scheloribates confundatus	31.1	61.9	6.3	5.9
Minunthozetes semirufus	55.2	74.3	87.0	93.7
Galumna nervosa	56.2	58.6	4.4	4.9
Ophidiotrichus borussicus	70.7	78.4	2.1	5.6
Achipteria coleoptrata	47.2	83.0	82.0	98.4
Pelops occultus	49.9	68.5	86.8	97.7
Peloptulus phaeonotus	32.0	42.0	20.9	10.1
Pseudotritia duplicata	59.6	35.4	2.1	1.3
Pseudotritia minima	54.4	38.5	2.7	4.4

Table 9. The proportion of explained variance and the relative position on the first principal axis for Mesostigmata in the November 1984 and the May 1985 samplings, respectively

	proportion of explained variance		position on the axis (range 1—100)	
	Nov. 1984	May 1985	Nov. 1984	May 1985
Zercon triangularis	59.8	69.7	12.1	4.4
Veigaia nemoralis	73.7	35.8	12.7	10.0
Paragamasus vagabundus	86.7	62.2	16.5	7.5
Dendrolaelaps rectus	31.9	41.8	77.7	94.2
Rhodacarus coronatus	74.5	68.9	15.4	5.6
Leioseius bicolor	39.4	36.7	36.6	17.0

44 % of the total variance in abundance of all species. The percentage of explained variance is also calculated for species according to the method described by Braak & Looman (1986). In table 7 the proportion of explained variance for the first axis is presented for Collembola species having an explained variance higher than 30 % on the first principal axis. The position on the axis is also given scaled from 0 to 100 whereby 0 corresponds with the highest C/N ratio, the lowest pH_{KCl}, the lowest potassium content of the top soil and the lowest density of vegetation cover observed. From all Collembola species only *Folsomia quadrioculata* yielded an explained variance higher than 30 % on the second principal axis and scored 80.7 in the November sample and 85.0 in the May sample on a 0 to 100 scale. Zero corresponds with the lowest fraction of organic matter observed. The scores on the first and second principal axes of the Cryptostigmata are showed in fig. 4 and 5. The first and second principal axis together explain 41.3 % and 45.0 % in the November and May sample, respectively. The first axis is correlated with vegetation cover, nitrogen fertilization, pH_{KCl}, annual production of plant biomass, potassium content of the top soil and the C/N ratio. The second axis is correlated with the phosphate content of the top soil.

In table 8 the proportion of explained variance for Cryptostigmata species is presented. Seventeen species with an explained variance higher than 30 % have been selected. The position on the axis is given scaled 0 to 100 whereby 0 corresponds with the highest C/N quotient, the lowest pH_{KCl}, the lowest density of vegetation cover, the lowest annual production of plant biomass and the lowest nitrogen fertilization observed. Of all Cryptostigmatic species only *Platynothrus peltifer* scored higher than 30 % explained variance by the second principal axis in both the November and May samplings, 38.3 % and 53.5 %, respectively. The position of *P. peltifer* on the axis scaled 0 to 100 is 15.6 in the November sampling and 37.5 in the May sampling. Zero corresponds with the lowest phosphate content of the top soil observed.

The scores on the first and second principal axis of the Mesostigmata are shown in fig. 6 and 7. Both axes explain 33.0 % and 30.6 % of the total variance in numbers of Mesostigmata in the November and May samplings respectively. The first axis is correlated with nitrogen fertilization, pH_{KCl}, potassium fertilization, production of plant biomass, vegetation cover, and C/N ratio. The second principal axis is not significantly ($p > 0.05$) correlated with any of the environmental parameters. Six mesostigmatic species have a fraction higher than 30 % explained variance on the first axis in both the November and the May samplings (table 9). Also the position on the first axis is given scaled 0 to 100; 0 corresponding with the highest C/N ratio, lowest nitrogen fertilization, lowest pH_{KCl}, lowest potassium fertilization, lowest production of plant biomass and lowest density of vegetation cover. There are no species having in both the November and May samplings an explained variance higher than 30 % on the second principal axis.

For Astigmata and Trombidiformes together, both the first and second principal axes explain 40.6 % and 32.4 % of the total variance. The first axis is correlated with fertilization of nitrogen, potassium, and phosphate, pH_{KCl}, production of plant biomass and C/N ratio. The second principal axis is correlated with the phosphate content of the top soil. One astigmatic species, *Tyrophagus longior*, has in both the November and May samplings an explained variance by the first principal axis higher than 30 %, respectively 48.9 % and 57.5 %. *Tyrophagus longior* scores, on the first axis, scaled 0 to 100, 88.9 and 95.7 in the November and May samplings respectively. Two taxonomic groups of Trombidiformes have a fraction explained variance higher than 30 %, on the first principal axis: *Nanorchestes* species (71.7 % and 52.2 %) and the family Rhaphignathidae (56.9 % and 33.7 %). The numbers in brackets are the fractions of explained variance in the November and May samplings respectively. Both taxonomic groups are positively correlated with a high C/N ratio, a low pH_{KCl}, low fertilization of nitrogen, potassium, and phosphate and a low production of plant biomass, contrarily to *Tyrophagus longior* which is negatively correlated.

5. Discussion

We conclude that measures of diversity and evenness are not appropriate to express differences in microarthropod communities in differently managed grasslands. The differences are demonstrated with a multivariate analysis of variance. Canonical correspondence analysis shows a major influence of nitrogen fertilization. Mowing and grazing have minor importance. We qualify species as indicators when the explained variance in both the November and May samplings is above 30 % on the first canonical axis.

A practical problem is the correlation among several environmental factors. Especially correlations among environmental factors correlated with the first canonical axis impede a clear interpretation of the results. The first canonical axis is positively correlated in most cases with nitrogen fertilization, vegetation cover, biomass production, C/N ratio and *p*H. The first three factors are in practice always correlated as a result of nitrogen fertilization. C/N ratio and *p*H are connected with nitrogen fertilization (Tischler, 1965) but they might also have many other causes. To discriminate between the effects of *p*H, C/N ratio and nitrogen fertilization, these factors should be separated in a new design using different fertilizers. We have to bear in mind that the presented indicator species might be indicators of *p*H or of fertilization. Some Collembola appear to be influenced by *p*H. *Isotomiella minor* has been found more abundant at *p*H = 4.6 than at *p*H = 4.1 (Bååth *et al.*, 1980). Hågvar (1982) found *I. minor* at a range of *p*H values having a preference for *p*H = 4.5. Hågvar & Kjøndal (1981) and Hågvar (1984a) showed a significant higher number of *I. minor* at *p*H = 3—5 that at *p*H = 2. *Isotoma sensibilis* has been found only in acid plots (*p*H = 3.7) (Hågvar, 1982). Bååth *et al.* (1980) observed a slight increase in numbers of *Isotoma viridis* in acidified plots. The range of *p*H values in the grasslands we have investigated is pH_{KCl} = 3.5—5.8. *Isotomiella minor* and *Isotoma sensibilis* are found at plots having the lowest *p*H. *Isotoma viridis* occupies the whole range being most abundant at the higher *p*H values. Except for *Isotoma viridis*, the results agree with those of acidification experiments, taking into account that the pH_{KCl} is usually lower than the pH_{H_2O}. In the case of *Isotoma viridis* fertilization has probably a more dominant effect than has *p*H. Hvgvar & Abrahamsen (1984) found a positive correlation between total soil nitrogen and the abundance of *Isotomiella minor*, which could not be observed in our results. A positive relation between total soil potassium and the abundance of *Folsomia quadrioculata* found by Hågvar & Abrahamsen (1984) might also be observed in our results (fig. 2 and 3). Żyromska-Rudzka (1976) observed an increase of Apterygota due to fertilization. We observed an higher abundance at high fertilization levels in only three species (*Proisotoma minuta*, *Isotoma viridis*, and *Sminthurinus aureus*). The abundance of all Collembola is lowest at the highest fertilization level.

Acidification results in a decrease in numbers of Acari (Hågvar & Amundsen, 1981) which is also the case due to fertilization (Zyromska-Rudzka, 1976). In laboratory experiments Hågvar & Kjøndal (1981) could not detect a significant correlation between *p*H and abundance of *Nothrus silvestris*, *Platynothrus peltifer*, *Veigaia nemorensis*, and *Tyrophagus* spec. *Leioseius bicolor* increases in number at *p*H = 2. In nature *Nothrus silvestris* is more abundant at low *p*H values. Probably other factors are limiting for *N. silvestris* at higher *p*H values (Hagvar, 1984b). We conclude that fertilization plays a more important role in the abundance of Acari than *p*H does.

Siepel & van de Bund (1986) group Collembola according to their life forms and Acari according to their life history strategies, the former based on the work of Gisin (1943) and the latter based on the theory of Stearns (1976). At high fertilization levels the fraction of euedaphic Collembola is lower in favour of hemiedaphic and especially epedaphic species. This is in agreement with the observations of Edwards & Lofty (1974). In Acari the species having a long life cycle ($\geq$ 1 year) are less abundant at high fertilization levels. Fertilization does also change the species composition in favour of short lived species. Phoretic species having a short generation time are more abundant at high fertilization levels. Furthermore fertilization appears to have a strong reducing effect on the microarthropod fauna of grasslands on sandy soils.

Appendix 1. Soil characteristics and vegetation biomass per plant species of the grassland, under study.

Environmental variable	Grassland							
	1	2	3	4	5	6	7	8
Org. matter content [%]	10.5	5.5	3.5	7.4	5.8	6.6	4.1	8.0
C/N ratio	30.3	29.6	29.9	20.4	21.3	21.2	22.6	20.5
Total P [mg $P_2O_5 \times 100\ g^{-1}$]	57	40	26	48	59	45	32	75
Total K [mg $K_2O \times 100\ g^{-1}$]	9	5	5	19	11	15	15	17
*p*H KCl	3.3	3.5	3.6	4.6	4.6	4.8	5.4	5.8
Moisture content [%]	23	19	24	22	19	16	14	16
Vegetation cover [%]	35	65	45	85	85	85	45	80
Diversity vertical	0.14	0.09	0.11	0.07	0.05	0.07	0.07	0.07
Diversity horizontal	0.25	0.16	0.32	0.20	0.18	0.34	0.10	0.21
Total biomass [$g \times m^{-2}$]	134.9	222.6	182.7	590.3	946.0	165.6	140.7	280.7
per plant species [%]								
Bryophyta	18.9	29.1	34.7					
Lichenophyta	0.1	—	0.5					
Vaccinium myrtillus	4.8							
Calluna vulgaris	14.5							
Galium saxatile	5.1	5.8						
Carex pilulifera	0.4							
Avellana felexuosa	55.9	12.1	26.0					
Agrostis tenuis	0.4	13.0						
Rumex acetosella		3.3						
Potentilla erecta		0.1	—	3.1				
Genista pilosa		0.1						
Hypochaeris radicata		1.2	—	—	—	—	0.2	
Hieracium pilosella		0.1						
Luzula campestris		24.7						
Carex arenaria		0.9						
Festuca ovina		0.3						
Festuca rubra		3.7	—	0.6	0.1			
Molinia caerulea		1.0						
Holcus lanatus		2.2	—	4.2	38.1	31.0		
Aira praecox		2.3						
Corynephorus canescens		<						
Pinus sylvestris			0.1					
Vaccinium vitis-idaea			38.7					
Cerastium fontanum				5.5				
Ranunculus acris				0.2	3.4		0.6	
Glechoma hederacea				<	—	0.1		
Achillea millefolium				0.5				
Taraxacum spec.				0.5	2.0	—	—	0.6
Bromus mollis				0.7	0.2			
Poa annua				0.2	0.1	0.1	18.3	10.6
Poa trivialis				2.0	1.5	0.4	0.9	17.9
Poa pratensis				<	0.1			
Dactylis glomerata				15.5	—	—	9.0	0.1
Lolium perenne				9.4	9.2	52.3	70.9	49.2
Arrhenatherum elatius				50.3	7.7			
Holcus mollis				3.1	1.2	6.7		
Agrostis stolonifera				<	0.3			
Alopecurus pratensis				4.2	14.5	2.2		
Anthoxanthum odoratum				<	1.7			
Rumex acetosa					19.7			
Ranunculus repens					0.1	5.8	—	7.4
Trifolium repens					<	1.3	—	0.3
Leontodon autumnalis						0.2		
Alopecurus geniculatus								11.0

"Diversity vertical" is the coefficient of variation of vegetation height and "diversity horizontal" is the coefficient of variation of vegetation biomass per plot. Biomass of plant species is given as the proportion of the total biomass per grassland (< means less than 1 %).

6. Acknowledgements

We wish to thank the "Vereniging tot Behoud van Natuurmonumenten in Nederland" for their permission to work in the nature reserves "Deelerwoud" and "Imbos", the management fo the National Park "De Hoge Veluwe" for the "Heiweg" area and the Agricultural University Wageningen for the "Bovenbuurt", "Droevendaal" and "Dijkgraaf" grassland. Mr. A. J. Griffioen kindly prepared the figures.

7. References

Alatalo, R. V., 1981. Problems in the measurement of evenness in ecology. Oikos **37**, 199—204.

Bååth, E., B. Berg, U. Lohm, B. Lundgreen, H. Lundkvist, T. Rosswal, B. Söderström & A. Wiren, 1980. Effects of experimental acidification and liming on soil organisms and decomposition in a Scotch pine forest. Pedobiologia **20**, 85—100.

Baker, E. W., & G. W. Wharton, 1952. An introduction to acarology. MacMillan comp. New York.

Braak, C. J. F. ter, 1986. Canonical correspondence analysis: a new eigen vector technique for multivariate direct gradient analysis. Ecology **57**, 1167—1179.

— & C. W. N. Looman, 1986. Weighted averaging, logistic regression and the Gaussian response model. Vegetatio **65**, 3—11.

Edwards, C. A., & J. R. Lofty, 1974. The invertebrate fauna of the Park Grass plots. I. Soil fauna. Rothamsted Report for 1974, part 2, 133—154.

Elzebroek, A. T. G., 1982. Evolutie en gebruiksmogelijkheden van grasvegetaties bij extensivering van de exploitatie. Resultaten van tien jaar onderzoek. Med. no. 69. Vakgroep Landbouwplantenteelt en Graslandkunde. L. H. Wageningen.

Gisin, H., 1943. Oekologie und Lebensgemeinschaften der Collembolen im schweizerischen Exkursionsgebiet Basels. Rev. Suisse Zool. **50**; 131—224.

— 1960. Collembolenfauna europas. Museum d'histoire naturelle, Genève.

Hågvar, S., 1982. Collembola in Norwegian coniferous forest soils. I. Relations to plant communities and soil fertility. Pedobiologia **24**, 255—296.

— 1984a. Effects of liming and artificial acid rain on Collembola and Protura in coniferous forest. Pedobiologia **27**; 341—354.

— 1984b. Six common mite species (Acari) in Norwegian coniferous forest soils; relations to vegetation types and soil characteristics. Pedobiologia **27**, 355—364.

— & G. Abrahamsen, 1984. Collembola in Norwegian coniferous forest soils III. Relations to soil chemistry. Pedobiologia **27**, 331—339.

— & T. Amundsen, 1981. Effects of liming and artificial rain on the mite (Acari) fauna in coniferous forest. Oikos **37**, 7—20.

— & B. R. Kjøndal, 1981. Effects of artificial acid rain on the microarthropod fauna in decomposing birch leaves. Pedobiologia **22**, 409—422.

Hammen, L. van der, 1952. The oribatei (Acari) of the Netherlands. Thesis Brill, Leiden, 139 p.

Hill, M. O., & H. G. Gauch, 1980. Detrended correspondence analysis: an improved ordination technique. Vegetatio **42**, 47—58.

Höller, G., 1962. Die Bodenmilben des rheinischen Lösslehms in ihrer Abhängigkeit von Düngung und anderen Standortfaktoren. Mitt. angew. Ent. **18**, 44—79.

Höller-Land, G., 1962. Die Abhängigkeit der bodenbewohnenden Collembolen von Düngung und anderen Standortfaktoren unter Dikopshofer Verhältnissen. Mitt. angew. Ent. **18**, 80—120.

Hughes, A. M., 1976. The mites of stored food and houses. Technical Bulletin, Min. of Agr. Fish and Food, London.

Hurlbert, S. H., 1971. The nonconcept of species diversity: a critique and alternative parameters. Ecology **52**, 577—586.

Karafiat, H., 1959. Systematik und Oekologie der Scutacariden. Beiträge zur Systematik und Oekologie mitteleuropäischen Avarina. Band 1, 627—712. Geest & Portig, Leipzig.

Karg, W., 1971. Acari (Acarina), Milben. Unterordnung Anactinochaeta (Parasitiformes). Die freilebenden Gamasina (Gamasides). Raubmilben. Die Tierwelt Deutschlands **59**, 1—475.

King, K. L., & K. J. Hutchinson, 1976. The effects of sheep stocking intensity on the abundance and distribution of mesofauna in pastures. J. appl. Ecol. **13**, 41—55.

— K. J. Hutchinson & P. Greenslade, 1976. The effects of sheep numbers on associations of Collembola in sown pastures. J. appl. Ecol. **13**, 731—739.

Krczal, H., 1959. Systematik und Oekologie der Pyemotiden. Beiträge zur Systematik und Oekologie mitteleuropäischer Acarina. **1**, 385—625. Geest & Portig, Leipzig.

Marshall, V. G., 1977. Effects of manures and fertilizers on soil fauna: a review. Special publication nr. 3. Commonwealth Bureau of Soils, London. 79 p.

Pielou, E. C., 1969. An introduction to mathematical ecology. Wiley, New York. 286 pp.

Rotenberry, J. T., 1978. Components of avian diversity along a multifactoral climatic gradient. Ecology **59**, 693—699.

Rottman, R. J., & J. L. Capinera, 1983. Effects of insect and cattle induced perturbations on a shortgrass prairie arthropod community. J. Kansas Ent. Soc. **56**, 241—252.

Scheucher, R., 1959. Systematik und Oeokologie der deutschen Anoetinen. Beiträge zur Systematik und Oekologie mitteleuropäischer Acarina. **1**, 233—384. Geest & Portig, Leipzig.
Seber, G. A. F., 1984. Multivariate observations. Wiley, New York, 686 pp.
Sellnick, M., 1928. Hornmilben, Oribatei. **In:** Tierwelt Mitteleuropas. **3** (9); 42 p. Quelle & Meyer, Leipzig.
Sellnick, M., 1960. Formenkreis: Hornmilben, Oribatei. Die Tierwelt Mitteleuropas **3,** Teil 9 Ergänzung: 45—134. Quelle & Meyer, Leipzig.
Siepel, H., & C. F. van de Bund, 1986. The use of life-history strategies of microarthropods in grassland management. *In:* Velthuis, H. W. W. (ed.), Proc. of the third European Congres of Entomology, Amsterdam, 481—484 pp.
Southwood, F. R. E., & H. F. van Emden, 1967. A comparison of the fauna of cut and uncut grasslands. Z. angew. Ent. **60**, 188—198.
Stearns, S. C. 1976. Life-history tactics: a review of the ideas. Quart. Rev. Biol. **51**, 1, 3—47.
Tischler, E. 1965. Agrarökologie. Fischer Jena, 499 pp.
Tol, J. van, 1983. Handleiding en atlas voor het medewerken aan entomologische projection van de European Invertebrate Survey. Rijksmuseum voor Natuurlijke Historie, Leiden.
Türk, E., & F. Türk, 1959. Systematik und Oekologie der Tyroglyphiden Mitteleuropas. Beiträge zur Systematik und Oekologie mitteleuropäischer Acarina. **1**, 1—231. Geest & Portig, Leipzig.
Walsingham, J. M., 1976. Effect of sheepgrazing on the invertebrate population of agricultural grassland. Sc. Proc. R. Dubl. Soc. Ser. **A** 6, 11, 297—304.
Żyromska-Rudzka, H., 1976. The effect of mineral fertilization of a meadow on the oribatid mites and other soil mesofauna. Pol. ecol. Stud. **2**, 157—182.

Address of the authors: H. Siepel (corresponding author), Research Institute for Nature Management, P.O. Box 9201, NL - 6800 HB Arnhem, The Netherlands.

Synopsis: *Original scientific paper*

Siepel, H., & C. F. van de Bund, 1988. The influence of management practices on the microarthropod community of grasslands. Pedobiologia **31**, 339—354

The effects of management measures for grasslands such as fertilization, mowing, and grazing on the microarthropod fauna are studied. The microarthropod fauna is sampled twice a year on grassland sites with different management. The microarthropods are extracted by means of a Tullgren funnel. Almost all microarthropods are identified to species level.

Differences in microarthropod communities among sites having a special management are shown by multivariate analysis of variance. Diversity and evenness measures do not appear appropriate to express these differences.

Environmental factors yielding the major part of the variance in abundance of microarthropods are traced using canonical correspondence analysis. Species having a season-independent response to the principal environmental factors are presented as indicator species. High nitrogen fertilization, among some correlated factors, corresponds with a decrease in number of species and a low abundance of microarthropods.

Key words: grassland, management, fertilization, mowing, grazing, Collembola, Acari, correspondence analysis, canonical correspondence analysis.